GROUND WATER IN PARADISE VALLEY, ARIZONA.

By O. E. MEINZER and A. J. ELLIS.

INTRODUCTION.

Paradise Valley is situated north of Phoenix, in Maricopa County, Ariz. (see fig. 7), between the Phoenix Mountains on the west and the McDowell Mountains on the east. At the north end it is terminated by a rocky upland, but on the south it opens into the Salt River valley. If the Arizona canal is taken as its southern boundary, it is approximately 20 miles long and 10 miles wide and has an area of about 200 square miles. Cave Creek, an intermittent stream that drains about 225 square miles of mountainous country north of Paradise Valley, formerly no doubt flowed southward through Paradise Valley but now flows across only the northwest corner of this valley and reaches the Salt River valley through a gap in the Phoenix Mountains and through Deer Valley, which lies west of these mountains. (See Pl. III.) Paradise Valley is closely related to Cave Creek in both its physiographic history and its ground-water supply, and the entire drainage basin of Cave Creek is therefore included in the area discussed in this paper.

The present population of the area under consideration consists of a number of recent settlers in Paradise Valley south of the old Verde canal (see Pl. III), a few old settlers and homesteaders in the vicinity of Cave Creek station, and a number of miners and prospectors at the Union mine and elsewhere in the mountains. A stage that carries the mail runs from Phoenix to Cave Creek station by way of Montgomery and the Union mine. The distance by wagon road from Phoenix to Montgomery is 12 miles, and the distance from Phoenix to Cave Creek station is 29 miles. Scottsdale, which contains a post office, a general store, and a telephone office, is situated immediately south of the Arizona canal and is easily reached from the southern part of the valley.

One of the most notable features of Paradise Valley is the abandoned Verde canal, which lies just above a large tract of excellent agricultural land in the heart of the valley and which, although now of no practical value, gives a powerful stimulus to the imagination of one who is endeavoring to visualize the transformation that could be wrought in this part of the valley if an adequate water supply were available. This canal was built about 20 years ago by the Rio Verde Canal Co. with the expectation of utilizing water from Verde River. The project involved the construction of a dam on Verde River at the site known as the Horseshoe reservoir, in T. 8 N., R. 6 E., a diversion

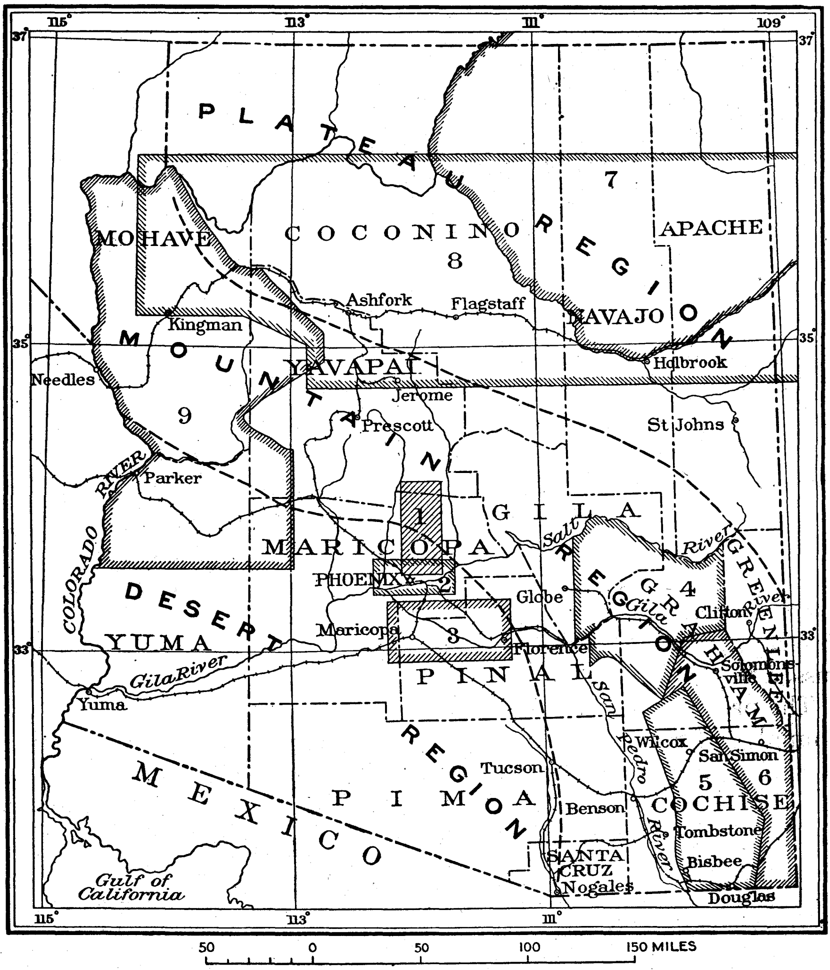
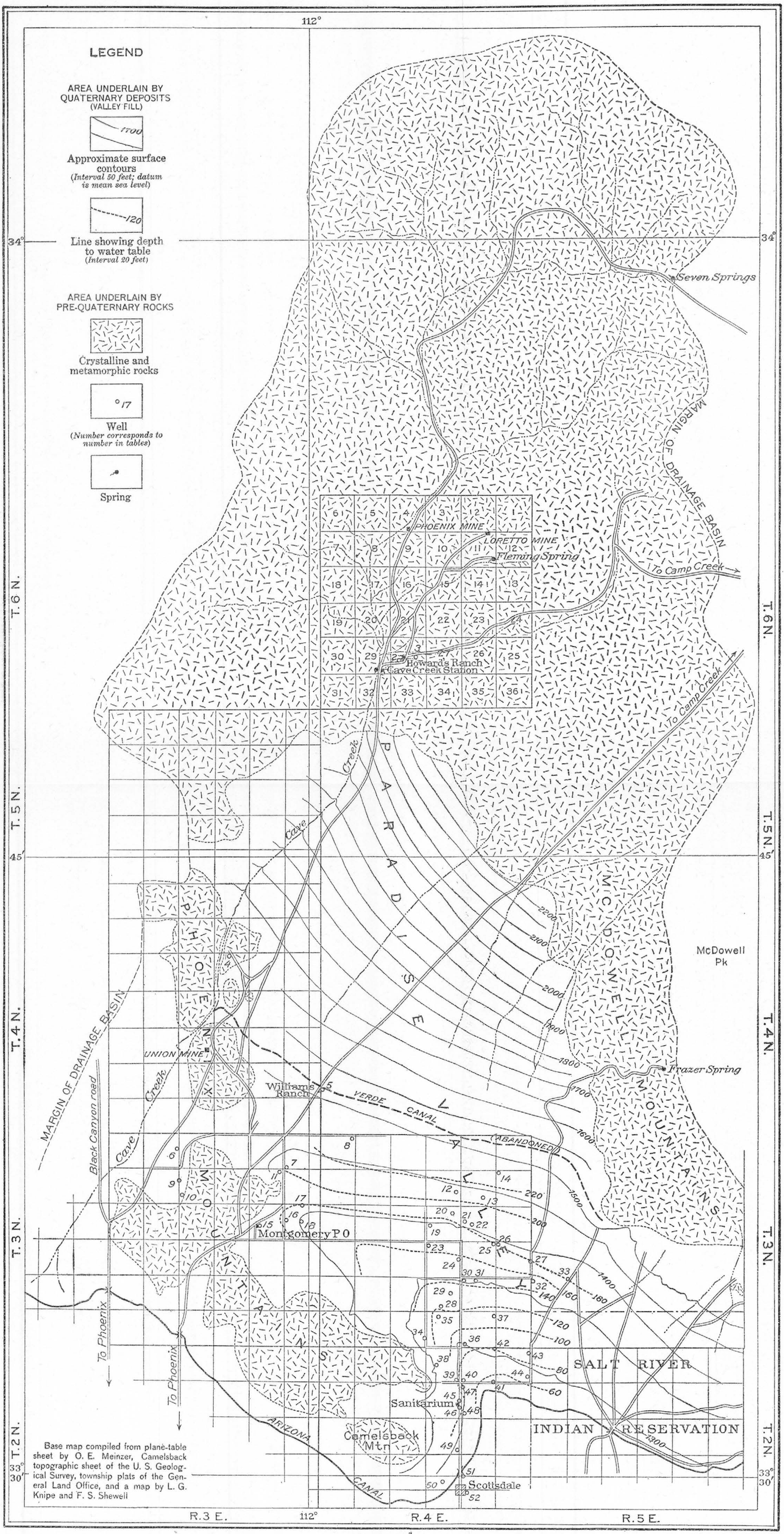


FIGURE 7.—Map of Arizona showing physiographic provinces (after Ransome) and positions of Paradise Valley and other areas described in ground-water papers of the United States Geological Survey.

1. Paradise Valley (the present paper).
2. Water-Supply Paper 136.
3. Water-Supply Paper 104.
4. Water-supply paper in preparation.
5. Water-Supply Paper 320.
6. Water-supply paper in preparation.
7. Water-supply paper in preparation.
8. Bulletin 435.
9. Bulletin 352.

dam 18 miles below the Horseshoe reservoir, and a canal 69 miles long extending from the diversion dam through Paradise Valley and across Cave Creek to New River. The estimated cost of the work was about $2,000,000, and the area to be brought under irrigation was estimated at 125,000 acres, of which about 50,000 acres was in Para-



Scale $\frac{1}{187,500}$

1 0 1 2 3 4 5 6 7 Miles

1915

MAP OF PARADISE VALLEY AND CAVE CREEK DRAINAGE BASINS, ARIZONA, SHOWING GROUND-WATER CONDITIONS.

dise Valley. A. P. Davis[1] wrote in 1897: "The magnitude of the undertaking, the natural difficulties to be overcome, and the prevailing business depression combine to render its prosecution a matter of peculiar difficulty." The canal was practically completed in its course across Paradise Valley, but work was discontinued when the company became involved in litigation over water rights, and it is now in ruins. The Salt River Valley Water Users' Association has made a filing on the available surplus waters of Verde River with a view to possible storage of these waters in the Horseshoe reservoir. This association has made borings of a dam site controlling the Horseshoe reservoir and may ultimately construct the dam. If such a dam is constructed, the water stored in the reservoir will belong to the Salt River project. According to F. W. Hanna, supervising engineer, there is no apparent feasible water supply from Verde River available for use in Paradise Valley.

At about the time the Verde canal was constructed the Pennsylvania Irrigation Co. had under consideration a project to build a dam 100 feet high in the canyon of Cave Creek, which, it was said, would form a reservoir holding more than 100,000 acre-feet, the water to be diverted about 7 miles below the dam and used in irrigating the lands in Paradise Valley above the line of the Verde canal. This project has, however, never been carried out. Davis[2] gave the following opinion in regard to it:

> As the drainage area is estimated to be only about 200 square miles, it seems improbable that this area will furnish sufficient water to justify the construction of a reservoir of this capacity, but a reservoir can doubtless be built at this point which will impound all the waters that can be depended upon from its drainage, and the land to be watered is abundant and excellent.

The present inhabitants of the valley are all recent settlers, most of whom have taken up homesteads. As there is no good prospect of obtaining any surface-water supply, and as the climate is too arid to permit successful dry farming, the settlers have appealed to the United States Government to develop, if possible, a ground-water supply for irrigation. The investigation on which this report is based was made as a result of a request for information from the Reclamation Service. The field work was done in August, 1914, and was completed within about 10 days.

For courtesies rendered in the collection of data for this report acknowledgments are due to Messrs. F. W. Hanna, of the United States Reclamation Service; L. G. Knipe, engineer, Phoenix, Ariz.; and S. L. Montgomery, Fred T. Weaver, George O'Clair, and C. B. Williams, of Paradise Valley. The water analyses were made at

[1] Davis, A. P., Irrigation near Phoenix, Ariz.: U. S. Geol. Survey Water-Supply Paper 2, p. 64, 1897. See also Schuyler, J. D., Reservoirs for irrigation: U. S. Geol. Survey Eighteenth Ann. Rept., pt. 4, p. 717, 1897.

[2] Davis, A. P., Irrigation near Phoenix, Ariz.: U. S. Geol. Survey Water-Supply Paper 2, p. 71, 1897.

the Arizona Agricultural Experiment Station by Mr. A. E. Vinson, through the courtesy of Mr. R. H. Forbes, director.

PHYSIOGRAPHY AND DRAINAGE.

Paradise Valley lies between the Phoenix and McDowell ranges and occupies a troughlike depression that has been partly filled by unconsolidated rock débris washed from the mountains. It appears to belong to the desert region rather than the mountain region, as described by Ransome.[1] (See fig. 7.)

The McDowell Mountains form an unbroken range extending from the Salt River valley nearly to the Camp Creek road, shown on the map (Pl. III), and in McDowell Peak they reach an elevation of 4,022 feet above sea level. The west flank of this range is about 3 miles wide and is gashed by numerous small canyons which during wet seasons discharge storm waters into Paradise Valley, but it contains no permanent streams and, so far as was ascertained, no spring except Frazer Spring, shown on Plate III. At its south end the range is surrounded by valley fill, but to the north and northwest it is bordered by an extensive plateau underlain by bedrock or covered with only a thin mantle of rock waste. This rock-floored plateau, lying between the north end of the McDowell Mountains and a group of conspicuous peaks in the vicinity of Cave Creek, rises gently toward the northeast and forms an extension of the smooth constructional surface of the valley, although cut to a greater extent by gullies. Its width in the direction of the drainage lines is about 8 miles, and it therefore discharges a large amount of storm water into the valley.

Farther north and northwest there is an area of about 225 square miles of hills and ridges which was not examined except near its south end but which is known to be tributary to Cave Creek. (See Pl. III.) Cave Creek is normally dry but has an underflow that appears at the surface at Cave Creek station and sinks to unknown depths a short distance below the station. The creek carries large quantities of water after heavy storms of the summer rainy season and during parts of the winter season. The magnitude of the largest floods is shown by the broad streamway, the long distance that bowlders have been transported, and other evidences of high water. It is said that in exceptional freshets the water from Cave Creek has flooded parts of Phoenix.

The Phoenix Mountains, which lie west of Paradise Valley and extend from the Arizona canal northwestward to the mountainous region above Cave Creek station, rise abruptly from the valley floor but reach elevations of only 2,000 to 3,000 feet above sea level. This low range has no washes of considerable size that discharge into

[1] Ransome, F. L., U. S. Geol. Survey Geol. Atlas, Bisbee folio (No. 112), p. 1, 1904.

Paradise Valley. So much of it has been buried by the sediments washed from the mountainous areas north and east of Paradise Valley that its low gaps no longer stand above the general level of the valley fill. Hence the range is no longer an effective drainage divide but is at present crossed by the channel of Cave Creek.

The valley floor is a smooth, unbroken plain, somewhat fan-shaped at its north end and sloping gradually southward. It is about 2,200 feet above sea level at its north end and about 1,300 feet at the Arizona canal, where it merges with the broad plain of the Salt River valley. As shown by the contour lines on Plate III, the valley floor north of the Verde canal is convex in profile from the McDowell Mountains to Cave Creek and consists of a broad compound alluvial fan built by Cave Creek and the smaller drainage lines farther east. South of the Verde canal, however, the valley floor is concave in cross profile and the axial draw extends southeastward along the west side of the valley, its asymmetrical position being due to the greater contribution of sediment from the east than from the west.

Paradise Valley was no doubt formerly the valley of Cave Creek, and its deep deposit of fill was in large part supplied by that stream. The filling of the valley progressed until its floor was level with the notches in the mountains north of the Union mine. The heavy deposits of sediments from the relatively large draws that enter the north end of the valley east of Cave Creek formed a large fan that crowded the channel westward until the stream found an outlet through a narrow, tortuous gap between the partly buried hills. Before the valley surface had been built up to the level of this gap the creek no doubt flowed southward along the east border of these hills and thence followed approximately the course of the present axial draw. Before it took its present course through the hills it may have escaped westward through the wider gap 2 miles south of the Union mine. The divide in Paradise Valley between Cave Creek and the axial draw that drains most of the valley is extremely low and indefinite, and some of the streamways probably discharge water in both directions.

GEOLOGY.

Pre-Quaternary rocks.—The Phoenix and McDowell ranges are composed of igneous and metamorphosed sedimentary rocks, including granites, gneisses, schists, slates, and quartzites, which are tilted at high angles and have a prevailing southeastward dip. There are several hills consisting of vesicular basalt just north of the intersection of the Verde canal with Cave Creek, and a few similar bodies of basalt appear at the north end of the valley and in the southern part of the McDowell Range. The denuded surface between the north end of the McDowell Mountains and Cave Creek consists chiefly of a very coarse grained granite, composed of orthoclase, quartz, and biotite, which yields readily to weathering. These formations constitute the rock rim which incloses Paradise Valley, and they probably extend under the fill, forming the rock floor of the valley itself.

Quaternary deposits (valley fill).—The valley floor is the surface of a fluviatile deposit of unconsolidated arkosic or partly decomposed rock débris, with lenses of gravel and clay. This deposit has been derived from the adjacent mountains and especially from the region lying north of the valley. The fill increases in thickness southward from the outcrop of the bedrocks in the north and reaches a great depth in Salt River valley. None of the borings in the middle of Paradise Valley have reached bedrock, although some of them extend to depths of several hundred feet (see table, p. 70), and the maximum depth of the fill is therefore unknown.

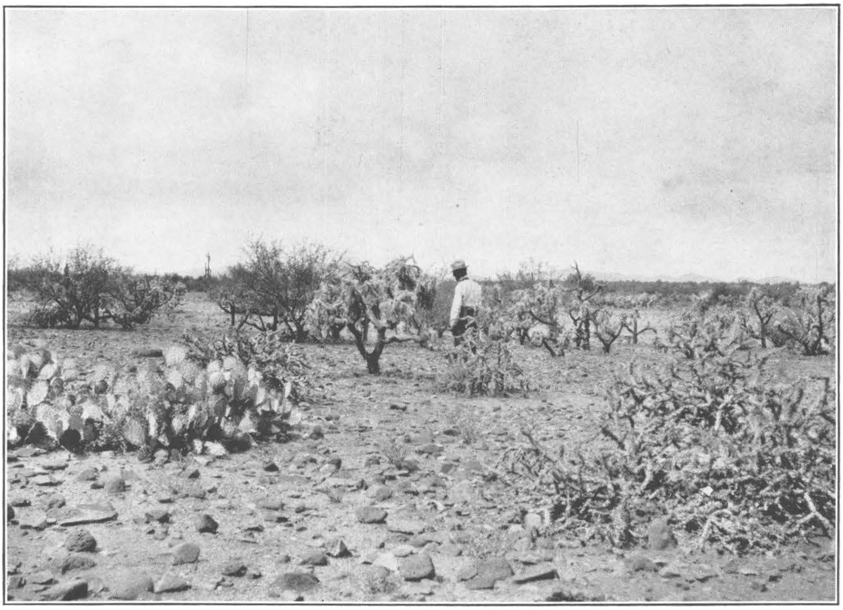
Where Cave Creek crosses the northwest corner of the valley, about 10 feet of loosely cemented conglomerate which contains bowlders as much as 12 inches in diameter is exposed in the creek bank. (See Pl. III and Pl. V, *B*, pp. 52, 56.) Similar beds have been encountered in some of the wells in the southern part of the valley at various depths from 100 to 300 feet or more. In Henry Crowe's well, in the interior of the valley (No. 31, p. 70, and Pl. III), bowlders several feet in diameter are said to have been reached. These deposits probably mark former courses of Cave Creek at times when its transporting power was unusually great, but they may have been in part deposited by lateral streams or wash from the Phoenix or McDowell mountains.

Caliche, or lime hardpan, is exposed in the marginal parts of the valley and was encountered in wells in the interior of the valley. Some wells penetrate several layers of caliche that are separated from one another by deposits of less thoroughly cemented valley fill.

SOIL AND VEGETATION.

The soil over most of the valley is a brownish loam, generally containing a few pebbles and small fragments of such rocks as those surrounding the valley. It is of good physical constituency and would no doubt make fertile soil for agriculture. Adjacent to the mountains there is a narrow belt of coarse gravelly soil which is not sufficiently disintegrated to be suitable for cultivation.

Mesquite, creosote bush, and palo verde make up in large part the flora on the loamy soil, and cacti of various species, including the giant cactus and the cholla, occupy the gravelly soils at the margins of the valley and on the adjacent uplands. (See Pl. IV.) Except for the cacti the mountains support only very sparse vegetation. In general mesquite and palo verde grow in this valley to heights of only 5 or 6 feet, but some of them in the vicinity of stream courses



A. SOIL AND VEGETATION OF GRAVELLY UPLANDS AT NORTH EDGE OF PARADISE VALLEY, ARIZ.

B. SOIL AND VEGETATION AT INTERMEDIATE LEVELS IN PARADISE VALLEY, ARIZ.

reach heights of nearly 20 feet, having trunks over 4 feet in circumference near the base. (See Pls. IV, *B*, and V, *A*.) The largest measurements of circumference obtained were 4.5 feet for mesquite and 4.7 feet for palo verde, with estimated heights of 15 feet and 18 feet respectively. The specimens having these dimensions were growing in the bed of the Verde canal, where flood waters accumulate, and they were therefore exceptionally well watered but not more than about 20 years old.

CLIMATE.

Paradise Valley is situated on the border between the mountain and desert regions of southern Arizona, as shown in figure 7, and its climate, while partaking of the characteristics of that prevailing throughout the Gila and Salt River valleys, is somewhat less torrid, owing to its higher altitude and its proximity to the mountains. The general climatic conditions are described in a report of the United States Weather Bureau [1] as follows:

Over the lower elevations embraced principally in the southwestern part of Arizona, including the valleys of the lower Colorado and Gila rivers, with elevations from a few feet to less than 3,000 feet above sea level, the summer heat as registered by the thermometer appears torrid in character, frequently rising above 100° and at times to 120° in the shade during the days of the warmer months of the year. The relative dryness of the atmosphere, due to its capacity for absorbing moisture at such high temperatures, and the cooling effect of the intense evaporation as felt by animal life cause the sensible temperature to appear many degrees lower than that indicated by the thermometer, and the usual outdoor occupations may be pursued with little more discomfort than in regions considered much cooler, if an adequate supply of water is provided to replace the moisture lost so rapidly from the body by evaporation.

As in all arid countries the range in temperature between day and night is large, and despite the intense heat registered during the day the nights are generally comfortable.

The precipitation occurs principally during two portions of the year, a primary maximum fall occurring during the months of July to September, inclusive, and a secondary maximum during the colder months of the year. But little precipitation occurs during the later autumn months and practically none at the lower elevations during April, May, and June.

Weather observations were made at Cave Creek station from July, 1909, to May, 1912, and in the south-central part of Paradise Valley since June, 1913. As shown in the diagram (fig. 8), the maximum temperatures at Cave Creek station are practically the same as at Phoenix, but the minimum temperatures are consistently lower at Cave Creek, the differences ranging from 2° to 15°. The record for Paradise Valley (see fig. 9) also shows a greater range than that for Phoenix, the maximum temperatures being generally 1° to 3° higher and the minimum 1° to 5° lower. The period covered by the record from Paradise Valley includes only one winter season, and the lowest temperature reached during this time was 29° F. The

[1] Summaries of climatological data by sections: U. S. Weather Bureau Bull. W, vol. 1, p. 21, 1912.

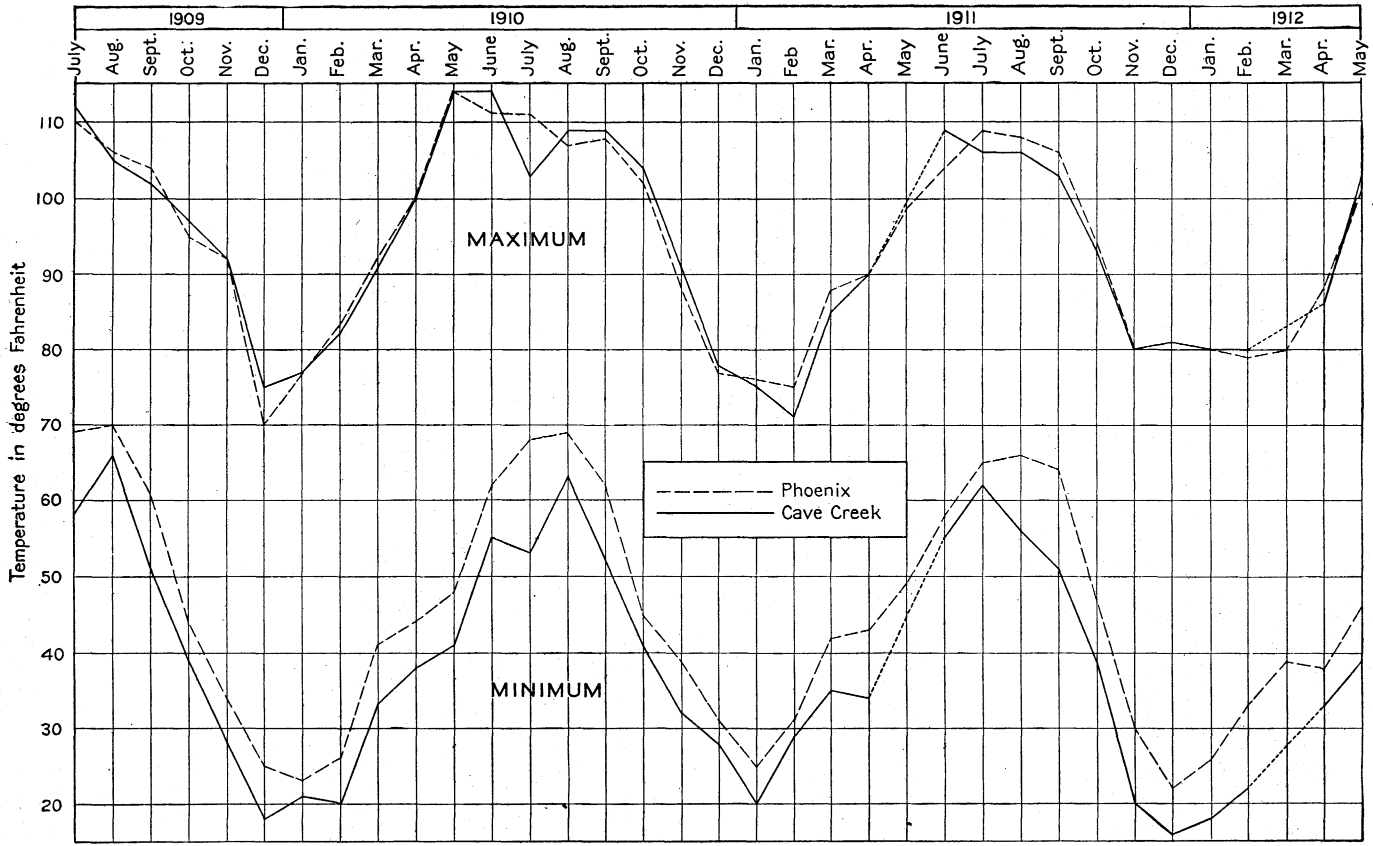


FIGURE 8.—Diagram showing relation between maximum and minimum monthly temperatures at Cave Creek and Phoenix during months when observations were made at both places.

lowest temperature at Phoenix during the same period was 30° F., but the complete record shows that at Phoenix the temperature falls to 25° F. or lower during normal winters, and it is therefore probable that temperatures of 20° to 25° F. are reached in normal winter

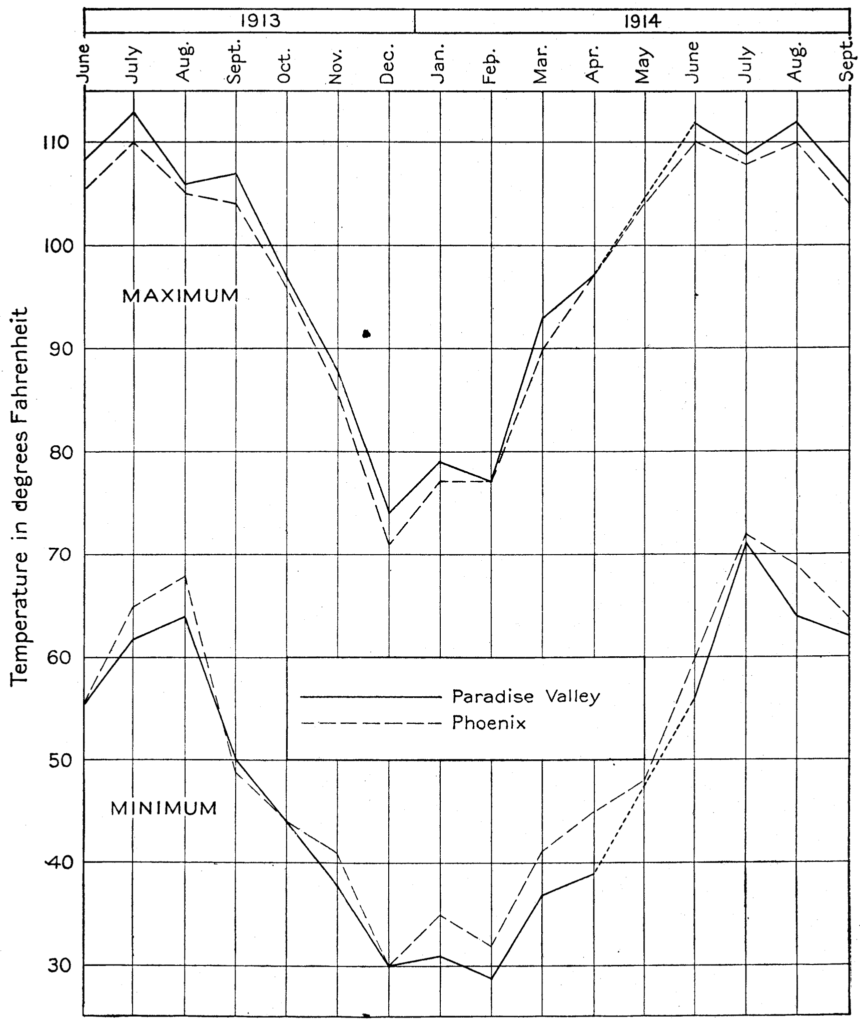


FIGURE 9.—Diagram showing relation between maximum and minimum monthly temperatures in Paradise Valley and Phoenix during months in which observations were made at both places.

seasons in Paradise Valley. The minimum winter temperatures at Phoenix, according to records extending over the period from 1909 to 1914, inclusive (see fig. 10), are only slightly lower than those at Redlands, Cal., where the climatic conditions are eminently suitable for the culture of citrus fruit.

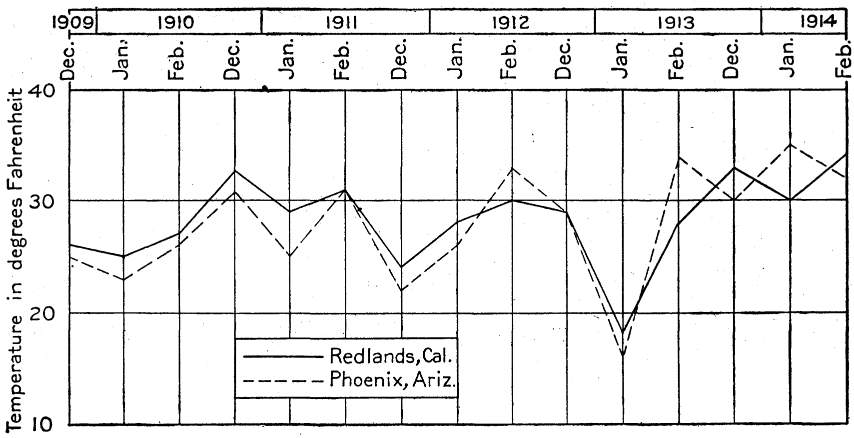


FIGURE 10.—Diagram showing relation between minimum temperatures in December, January, and February, 1909–1914, at Phoenix, Ariz., and Redlands, Cal.

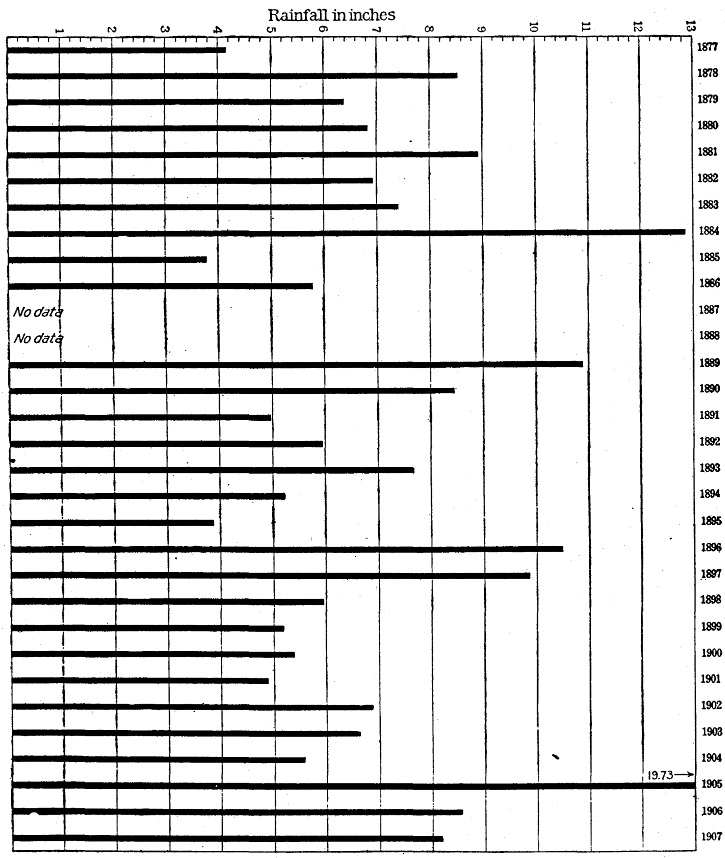


FIGURE 11.—Diagram showing total annual rainfall for 29 years, 1877 to 1907, inclusive, except 1887 and 1888, at Phoenix, Ariz.

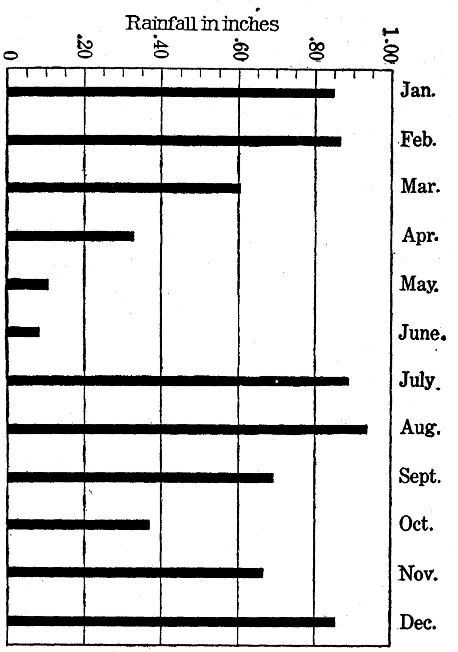


FIGURE 12.—Diagram showing mean monthly rainfall at Phoenix, Ariz. Length of record, 32 years—1876 to 1907.

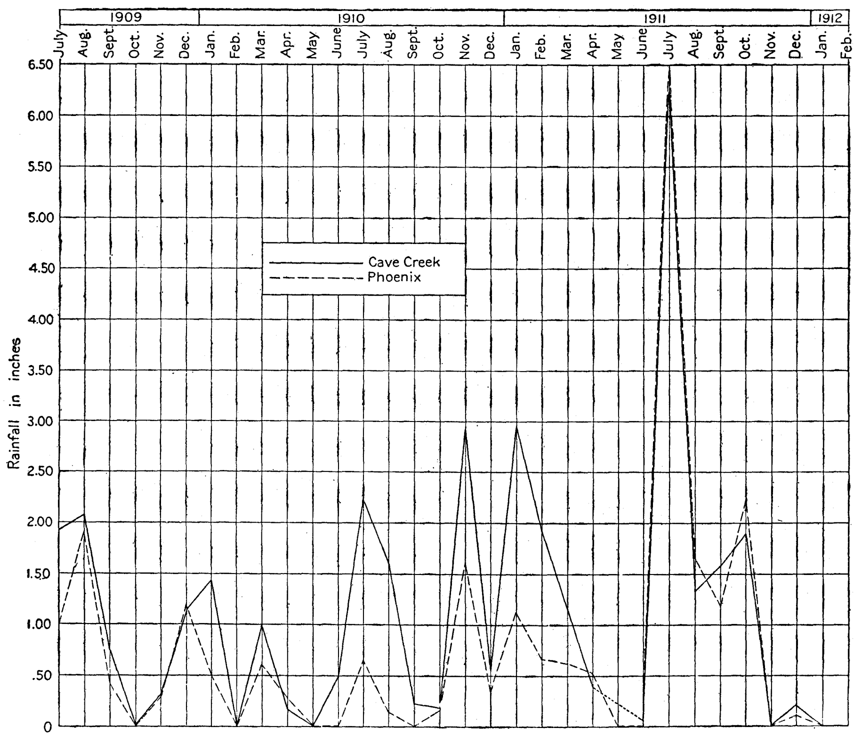


FIGURE 13.—Diagram showing relative amounts of rainfall at Cave Creek and Phoenix during months in which observations were made at both places.

The total annual rainfall at Phoenix, as determined by observations extending over a period of 29 years, ranges from 3.77 to 19.33 inches and averages 7.27 inches. (See fig. 11.) The mean monthly rainfall, as shown in figure 12, ranges from 0.08 to 0.94 inch, the minimum occurring in June and the maximum in August. A comparison of the rainfall at Phoenix with that at Cave Creek (fig. 13) shows a somewhat greater rainfall at Cave Creek. The same relation is shown in a comparison of the Paradise Valley record with that

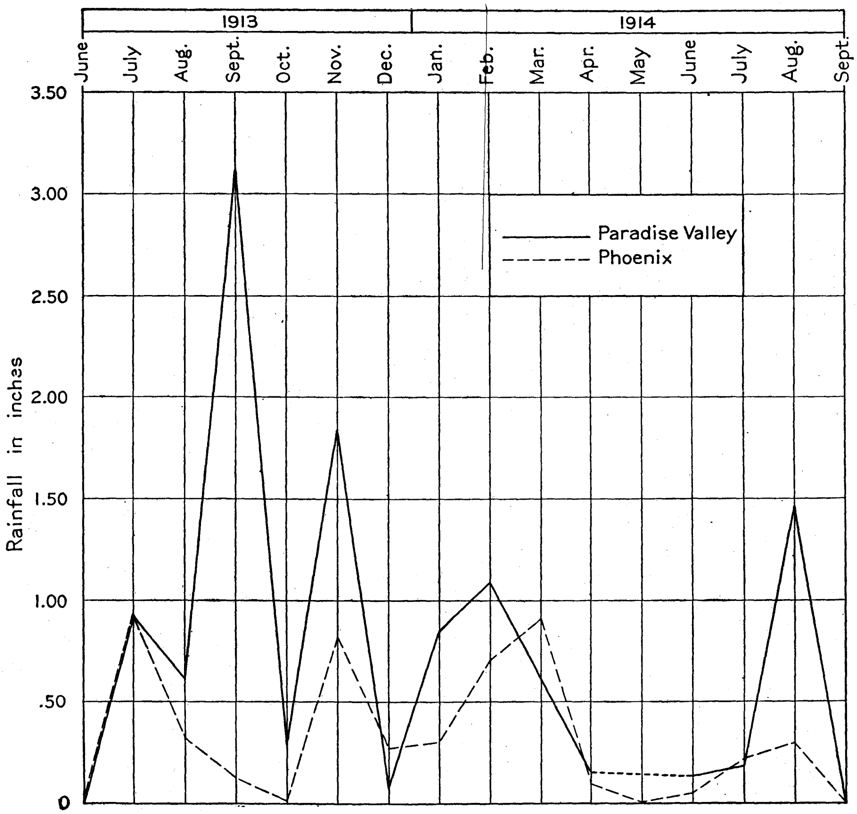


FIGURE 14.—Diagram showing relative amounts of rainfall at Paradise Valley and Phoenix during months in which observations were made at both places.

of Phoenix (fig. 14). The total rainfall recorded during the period of observations was for Paradise Valley 11.89 inches and for Phoenix 5.09 inches, a difference of 6.80 inches, but these figures are based on so short a record that they can not be said to represent general conditions.

OCCURRENCE OF GROUND WATER.

Paradise Valley occupies a rock trough partly filled with detritus which in its lower portion is saturated with water. The inclosing bedrock is practically impervious, its pore spaces being small and its resistance to percolation great. Even the joints and crevices in the rock do not generally furnish an outlet to the water but are commonly filled with water that does not escape.

In most parts of the mountainous area tributary to the valley there is a surficial porous zone of detritus and weathered bedrock, but this zone is normally dry except in a very few localities. The drainage area of Cave Creek north of Paradise Valley is reported to contain a few isolated springs. The McDowell Mountains have one spring on their west side, known as Frazer Spring, which in August, 1914, was flowing only about 3 gallons per minute. No springs were found in the Phoenix Mountains. The detritus in Cave Creek canyon in the vicinity of Cave Creek station contains water which is tapped by several shallow wells and infiltration ditches (see Pl. III and the table, p. 70), and a little water is found in the rock in the vicinity of the Union mine.

The detrital material underlying the valley, especially the gravelly portion, contains considerable pore space, and some of the water that falls on the valley surface or is shed from the mountain areas percolates between the grains and sinks to the bottom of the trough, where it accumulates and completely saturates the lower part of the valley fill. This body of ground water is confined on the east, north, and west by rock walls, although the west wall may not form a wholly effective barrier. At the south end it merges with the great body of ground water that underlies the Salt River valley. All wells sunk into the saturated zone have been successful, so far as information was obtained, but they have not been subjected to severe pumping tests. The gravel beds, which have been found pretty generally in drilling, are the most promising materials for large yields.

THE WATER TABLE.

The upper surface of the saturated zone is called the water table, and its position with respect to the surface of the ground is approximately indicated by the water level in wells. It is not a level plain like the surface of a lake but a slightly uneven surface with gentle slopes and undulations. The general shape of the water table and its approximate depth below the surface of the ground in Paradise Valley are indicated by lines on the map (Pl. III). As shown by these lines, the water table has the same general form as the surface of the ground, but the gradients are much less. For example, the slope of the land between O'Clair's ranch and the Arizona canal is about 150 feet, whereas the slope of the water table between these two places is only about 40 feet.

Along the Arizona canal the depth to the water table is 50 feet or slightly more, the depth probably decreasing gradually up the canal. Northward from this canal the depth increases as the land surface rises, until at Williams's ranch, on the abandoned Verde canal, the depth to the water table is 272 feet. In the region shown on the map (Pl. III) north of the Arizona canal and east of the Phoenix Mountains and Camelsback Mountain there is about 4,000 acres exclusive of the Indian reservation, or nearly 10,000 acres including the reservation, in which the depth to water is less than 100 feet.

North of the 100-foot line (see Pl. III) is a tract in which the depths to water range between 100 and 200 feet. This tract has an area of about 20,000 acres exclusive of the Indian reservation, or probably about 27,000 acres including the part of the reservation shown on the map. It extends westward almost to the Phoenix Mountains, as is shown by the facts that the depth to the water level is 195 feet at well No. 7, 200 feet at well No. 11, and 196 feet at Montgomery. (See Pl. III.)

Between the 200-foot line and the Verde canal the depth to water is generally less than 300 feet, but north of this old canal the depth no doubt becomes greater, as is indicated by the continuous rise of the land surface.

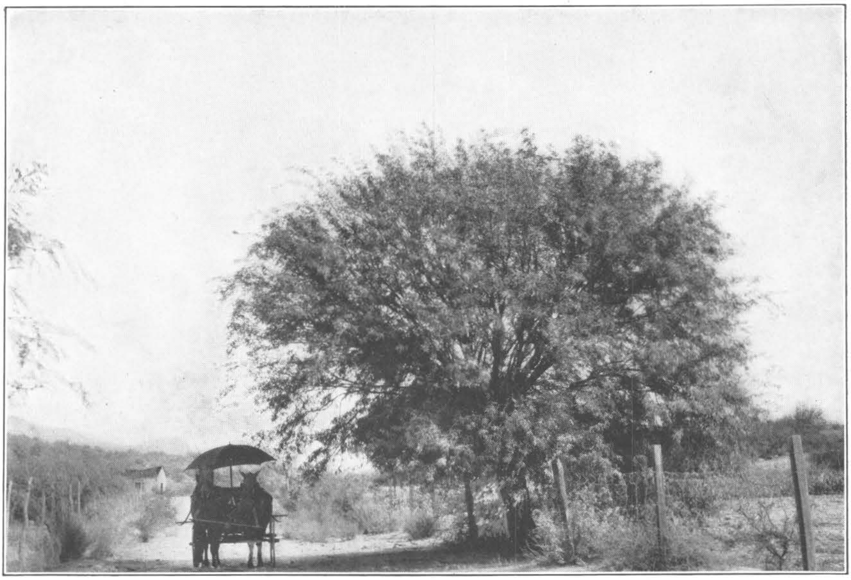
In the vicinity of Cave Creek station the ground water is held up by the bedrock and the water table therefore has no relation to that in Paradise Valley. The small underground reservoir in that vicinity constantly discharges water into Paradise Valley, but this water probably sinks rapidly when it reaches the valley fill, and the depth to the main body of ground water in the northern part of the valley is probably very great.

SOURCE AND DISPOSAL OF GROUND WATER.

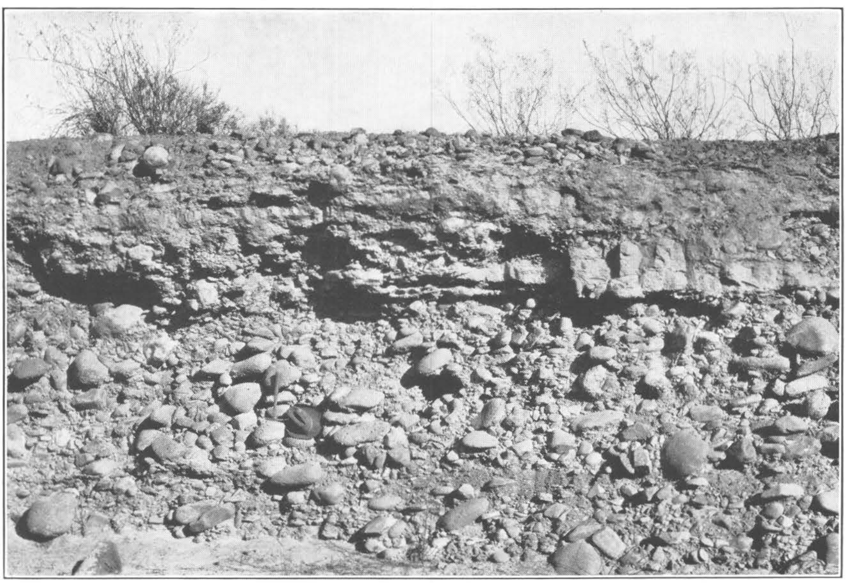
The main body of ground water, which saturates the valley fill below the water table, is supplied from the run-off and underflow of Cave Creek, the run-off from the mountain areas directly tributary to Paradise Valley, and the rain that falls on the valley.

The area of the Cave Creek drainage basin above the gap at Cave Creek station is about 225 square miles, and all the water discharged from this basin is poured into the northwest corner of Paradise Valley. From the locality where the creek enters Paradise Valley to the gap 4 miles north of the Union mine, where it leaves the valley, a distance of 7 miles (see Pl. III), its broad channel leads across coarse gravelly fill that appears to be very porous. This is well shown by the view in Plate V, *B*, which was taken near the lower end of the 7-mile stretch. Floods carrying the entire run-off of the drainage area of 225 square miles are from time to time discharged across this 7-mile stretch, and although much of the water reaches the gap and on rare occasions some of it gets as far as Phoenix, the conclusion can not be avoided that considerable flood water sinks into the gravelly deposits and is added to the ground-water supply of Paradise Valley.

In addition to the surface waters discharged into Paradise Valley by Cave Creek the ground water receives a continuous contribution



A. LARGE MESQUITE TREE WATERED BY UNDERFLOW OF CAVE CREEK, PARADISE VALLEY, ARIZ.



B. BANK OF CAVE CREEK IN PARADISE VALLEY, ARIZ., 6 MILES BELOW MOUTH OF CANYON, SHOWING CONGLOMERATE THAT FORMS GROUND-WATER INTAKE.

from the water that percolates downstream through the coarse detritus in Cave Creek canyon. Although this underground stream is small in volume compared with the surface streams, its relative importance as a source of ground water is probably not so small, for its flow is perennial, whereas the surface streams are temporary, and moreover its flow is apparently all contributed to the underground reservoir of Paradise Valley, whereas the proportion of the flood waters contributed is uncertain.

During the ages that Paradise Valley was gradually being built up by the deposition of rock detritus the course of Cave Creek through it must have been marked by beds of gravel which are now deeply buried but which head at the mouth of Cave Creek canyon and are therefore still in a favorable position to convey Cave Creek water. The lower part of the valley is two to three times as far from the mouth of the canyon as the point where the coarse gravel bed shown in Plate V, *B*, was observed, but in view of the facts that this gravel is very coarse, that gravel occurs much farther downstream, and that the gradient of Paradise Valley was no doubt steeper before so much filling had taken place than it is at present, it seems probable that the detritus along the ancient channels of the stream was coarse enough to be good water-bearing material even at the south end of the valley. This view is corroborated by the beds of gravel encountered in drilling.

If the average annual precipitation in the Cave Creek drainage basin above Cave Creek station is 10 inches the total quantity of water that falls on this basin in an average year is about 120,000 acre-feet. No data are available as to how much of this water is poured into Paradise Valley, and no estimate can be made of the proportion of it that is contributed to the underground supply. If only 1 per cent of the rainfall on the Cave Creek basin is converted into ground water underlying Paradise Valley the annual ground-water supply from this source is only 1,200 acre-feet; if 10 per cent is thus converted the annual supply is 12,000 acre-feet.

Owing to the impervious character of the rocks a large part of the water that falls as rain on the McDowell Mountains and other upland areas directly tributary to this valley is shed into the talus at the foot of the mountains or into the coarse fill near the margins of the valley and finally reaches the main body of ground water. On account, however, of the low rainfall and the small extent of the mountain areas, exclusive of the Cave Creek drainage basin, that are tributary to the valley, the amount of water received from this source is doubtless rather small.

Some of the water which falls as rain on the valley surface is also added to the body of ground water, but as the fill in the interior of the valley is rather compact and considerably cemented the contribution from this source may not be very large. Much of the water is absorbed by the dry soil and descends only a short distance. After the rainstorms it is returned to the surface by capillarity and there evaporated, or taken up by the roots of plants and restored to the atmosphere by transpiration.

The processes by which ground water escapes from an area are seepage into streams, evaporation from shallow-water tracts, transpiration, underflow, and seepage into bedrocks. To these natural processes must be added artificial removal through wells. In this valley the main body of ground water is too far below the surface to suffer losses by seepage into streams, evaporation, or transpiration, and owing to the impervious character of the bedrocks absorption by them can not be regarded as a considerable loss. The amount of water pumped is as yet also a negligible quantity. The gaps in the rock wall on the west side are probably not deep enough to extend below the water table, but the structure of the valley is favorable for free underflow southward into the Salt River valley. That there is such an underflow and that there is no underflow from the Salt River valley into Paradise Valley is also shown by the southward slope of the water table and by the much greater mineralization of the ground water in the Salt River valley than in Paradise Valley. (See pp. 67, 69.) The fact that the slope of the water table averages only about 5 feet to the mile in areas where data were obtainable indicates either that the water-bearing beds are very porous or that the annual recharge is small.

ARTESIAN PROSPECTS.

The character and structure of the bedrocks that are adjacent to Paradise Valley and that presumably underlie the valley fill render these rocks absolutely hopeless as a source of artesian water. All the requisite conditions for flowing wells are absent, as is very obvious from the description of the rocks on page 55.

The structure of the valley fill is such as to allow some of the water to acquire a small amount of head, but there is practically no prospect of obtaining flowing wells from the fill. In nine of the fifty wells in Paradise Valley concerning which information was obtained the water is known to have risen from 1 to 10 feet above the levels at which it was first struck. Such small rise is found in the fill of practically all western valleys that have been investigated. It may be explained in a general way as due to differences in the porosity of successive layers of fill and in the resistance of the water-bearing beds to the percolation of the water. Thus if the fill is traversed by buried gravelly channels of Cave Creek, as suggested on page 56, these old channels may be regarded as tubes that conduct water from the high levels of the northern part of the valley to the low levels of the southern part. Owing to the resistance to percolation by the gravelly materials that fill these tubes, the water in them may accumulate some head, but it is altogether improbable that the so-called tubes are so effectually plugged at their lower ends or that the incasing fill is so impervious as to allow the accumulation of enough pressure to raise the water to the surface when it is tapped by wells. In view of these conditions any attempt to obtain flowing wells by deep drilling would be altogether unwarranted.

QUALITY OF WATER.

In so far as is shown by the analyses in the accompanying table (p. 69), the ground waters of Paradise Valley, except near the Arizona canal, contain only moderate amounts of dissolved mineral matter, the total solids ranging from 216 to 430 parts per million. They are characterized in general by low contents of sulphate and chlorine and by a small excess of sodium over these acid radicles. This excess is shown in the analyses as sodium carbonate (Na_2CO_3), or black alkali. Waters of low mineralization but of the sodium carbonate type are characteristic of valley fill derived from granitic and metamorphic rocks such as are adjacent to this valley. There appears to be a slight increase in concentration southward, but without change in the type of water, as far as the edge of the Salt River valley, where the ground waters are much more highly mineralized and, as indicated by the analyses, have a large excess of sulphate and chlorine over sodium. This excess is indicated in the table as permanent hardness. The relations are shown in figure 15.

The waters from Mr. Houck's well (No. 1b) and Mr. Montgomery's well (No. 15) contain a little more mineral matter than the other samples from the valley, but they are also of good quality. The water from Mr. Montgomery's well is the only one north of the vicinity of the Arizona canal that is not reported to contain black alkali.

Enough analyses were made to show that the ground waters of Paradise Valley are of good quality for domestic and industrial uses and for irrigation. Of the common alkalies black alkali is the most injurious to crops, but the amounts of it found in the waters of this valley are too small to interfere seriously with agriculture or horticulture.

The samples taken where Paradise Valley opens into Salt River valley (Nos. 49, 51, and 52) contain so much common salt that they are of rather poor quality for irrigation. Their salinity and hardness also render them unsatisfactory for domestic and industrial uses. These samples resemble to some extent the ground waters of the Salt River valley in the vicinity of Phoenix, which are in general highly mineralized.[1]

[1] Lee, W. T., Underground waters of Salt River valley, Ariz.: U. S. Geol. Survey Water-Supply Paper 136, 1905.

The human system in this hot and arid climate requires large quantities of water, and it is therefore especially desirable to have water of good quality for drinking. The public supply of Phoenix, however, contains an undesirable amount of common salt and other mineral matter. It would probably not be practicable to obtain the entire

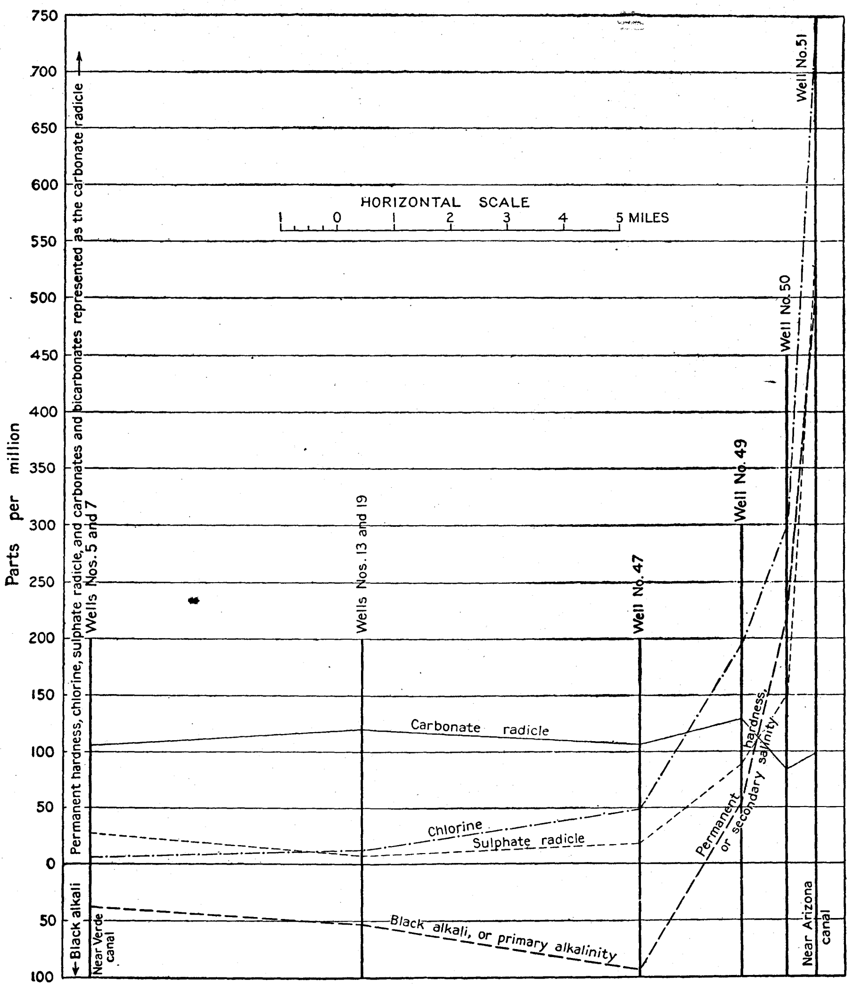


FIGURE 15.—Diagram showing the geographic variation in the quality of ground waters in Paradise Valley.

supply for this city from Paradise Valley, but the suggestion is here made that the cleanly and sanitary bottling of Paradise Valley well water for sale in Phoenix and other points in the Salt River valley might be developed into a profitable and beneficial industry.

The following table gives the analyses that were made during this investigation:

Analyses of well waters in Paradise Valley, Ariz.

[Samples collected by U. S. Geological Survey, August 29 to September 2, 1914, and analyzed at the laboratories of the Arizona Agricultural Experiment Station. Analyst, A. E. Vinson.]

No. of well.[a]	Owner.	Location.				Kind of well.	Depth of well.	Depth to water level.	Constituents, in parts per million.							Temperature of water.	Alkali coefficient.[b]	Classification for irrigation.[b]
		Quarter.	Section.	Township north.	Range east.				Total solids.	Carbonate radicle (CO_3).	Bicarbonate radicle (HCO_3).	Sulphate radicle (SO_4).	Chlorine (Cl).	Permanent hardness ($CaSO_4$).	Black alkali (Na_2CO_3).			
							Feet.	*Feet.*								° *F.*		
1b	J. D. Houck	SE	29	6	4	Dug	6	4	410	30	228	18	30	None.	8.5	73	58	Good.
5	C. B. Williams	SW	30	4	4	Drilled	310	....	216	None.	195	25	12	None.	34	78	33	Do.
7	George O'Clair	SW	1	3	3	...do	300	(?)200	244	18	187	30	2.4	None.	38	82	35	Do.
13	J. Lammers	SE	11	3	4	...do	....	....	240	24	187	8.2	12	None.	42	....	29	Do.
15	S. L. Montgomery	SW	14	3	3	...do	225	196	430	None.	183	47.0	61	5.4	None.	....	28	Do.
19	—— Lynn	SW	15	3	4	Dug	176	173	270	24	195	7.4	15	None.	59	....	22	Do.
47	Hattie Weaver	NW	11	2	4	Drilled	116	75	354	6	198	18	49	None.	93	....	11	Fair.
49	....	SE	15	2	4	...do	....	....	734	None.	256	88	193	54	None.	....	9.6	Do.
51	....	SW	23	2	4	....	60	....	1,020	None.	164	151	297	217	None.	....	6.8	Do.
52	Store, Scottsdale	NW	26	2	4	Drilled	....	....	2,640	None.	198	526	720	508	None.	....	6.3	Do.

[a] For further data in regard to these wells see pp. 70–72.

[b] Calculated according to Stabler's formulæ (Stabler, Herman, Some stream waters of the western United States: U. S. Geol. Survey Water-Supply Paper 274, pp. 177–179, 1911), modified as follows: If black alkali is reported, use Stabler's formula 13*c*, and compute sodium as follows: $Na = 0.4345\ Na_2CO_3 + 0.6488\ Cl + 0.4792\ SO_4$. If permanent hardness is reported and SO_4 equals or is less than $0.7059\ CaSO_4$, use Stabler's formula 13*a*. If permanent hardness is reported and SO_4 is more than $0.7059\ CaSO_4$, use Stabler's formula 13*b*. If formula 13*a* or 13*b* is required compute sodium as follows: $Na = 0.6488\ Cl + 0.4792\ (SO_4 - 0.7059\ CaSO_4)$.

WELLS.

In the last few years more than 50 wells have been sunk in Paradise Valley south of the Verde canal. Most of them were drilled by means of standard rigs and have diameters of 6 or 8 inches, but a considerable number were dug by hand and are several feet in diameter. Both in digging and in drilling wells it was found that the valley fill is sufficiently coherent to stand without curbing, and it is therefore customary to use only a few feet of casing in the tops of drilled wells. It would, however, be better practice to line the entire well with at least a sheet-metal casing in order to prevent deterioration by caving. On the whole, the wells do not extend far enough below the water table and have not been pumped hard enough to give an adequate test of the ground-water possibilities. For a discussion of irrigation wells, see page 72.

Detailed information in regard to the wells examined is given in the following table and the appended notes:

Records of wells in Paradise Valley.

Number on map.	Owner.	Location.				Kind of well.	Depth of well.	Depth to water level.	Diameter or cross section.	Yield per minute.
		Quarter.	Section.	Township north.	Range east.					
							Feet.	*Feet.*		*Gallons.*
1a	J. D. Houck	SE	29	6	4	Dug	16	12	5 by 5 feet	
1b	do	SE	29	6	4	do	6	4	4 by 4 feet	
2	E. A. Howard	SW	28	6	4	do	(*a*)			
3	W. H. Rheimer	SE	28	6	4	do	23	22		
5	C. B. Williams	SW	30	4	4	Drilled.	310	272	6 inches	5
6	—— Tymack	NE	5	3	3	do	200+			Low.
7	George O'Clair	SW	1	3	3	do	300	195	6 inches	20
8	Harvey Bell	NE	6	3	4	do	251	237	do	
9	—— Lyman	NE	8	3	3		280			
10	—— Hall	SE	9	3	3		160			
11	—— Nesbit	NE	11	3	3	Drilled.	235	200		
13	J. Lammers	SE	11	3	4	do				
14	—— Langley	NW	12	3	4		273	232		
15	S. L. Montgomery	SW	14	3	3	Drilled.	225	196	6 inches	18
16	—— Allee	NW	13	3	3		198	75		
17		(*b*)	13	3	3		400+			
18	—— Engel	Center	13	3	3		163			
19	—— Lynn	SW	15	3	4	Dug	176	173		
20	—— Pepper	NE	15	3	4		200	185		
21		NW	14	3	4	Drilled.		184		
23		NW	22	3	4	Dug	[c]100			
24	J. R. Brock		22	3	4	Drilled.	532	157		
25		NE	23	3	4	do				
26		NW	24	3	4	Dug	[c]60		4 feet	
27	Jasper Morgan	(*d*)	24	3	4		200	180+		
28	J. N. Green	SW	27	3	4	Drilled.	175	145		
29	Miss Green	NE	27	3	4	do	160	130		
30	—— Hover	NW	26	3	4	do	257	145		
31	Henry Crowe	(*e*)	26	3	4	Dug 146, drilled 100.	246	145		[f] 40
32	H. E. Pierce	NW	30	3	5	Drilled.		150	6 inches	
33	S. A. Allen	NE	30	3	5		198	180		
34	J. W. Smith	SE	33	3	4	Drilled.	141	102	6 inches	[f] 10–12
35	R. W. Gowey	NW	34	3	4	do	147	111		
36	Kelley Wright	SW	35	3	4		205			
37	A. Showers	NE	35	3	4	Dug 120, drilled 180.	300	108		

a Shallow.
b Middle of north margin.
c Well not completed.
d East central part.
e North central part.
f Reported by the drillers.

Records of wells in Paradise Valley—Continued.

Number on map.	Owner.	Location.				Kind of well.	Depth of well.	Depth to water level.	Diameter or cross section.	Yield per minute.
		Quarter.	Section.	Township north.	Range east.					
							Feet.	*Feet.*		*Gallons.*
39	Dr. La Rue	SE	3	2	4		116	85		
40	Fred T. Weaver	SW	2	2	4	Drilled.	121	75		a 13
41		SE	2	2	4	Dug		57		
42	J. T. Holmes	NE	2	2	4	Drilled.	160	80		
43	J. D. Bowers	NE	1	2	4	Dug	120	88		
44a	Mrs. A. J. Montgomery	SE	1	2	4	Drilled.	103	70	8 inches	a 50
44b	do	SE	1	2	4	do	103	70	do	a 50
45		NE	10	2	4		115	90		a Good.
46	Hans Weaver Sanatorium	SE	10	2	4	Drilled.	145	90	6 inches	a 20
47	Hattie Weaver	NW	11	2	4	do	116	75		
48	Mrs. Larsen	SW	11	2	4	do	100			
49		SE	15	2	4	do				
50	R. G. Hawkins	SW	22	2	4	Dug and drilled.	168	69	8 inches	a 750–900
51		SW	23	2	4		60			
52	Store at Scottsdale	NW	26	2	4	Drilled.				

a Reported by the drillers.

5. Penetrated loam containing several beds of caliche and at a depth of 272 feet reached a bed of water-bearing sand 7 feet thick, underlain by a layer of yellow clay, beneath which it entered a bed of coarse gravel that extends below the bottom of the well. Pumping plant consists of a single-acting cylinder pump, the cylinder being set 293 feet below the surface of the ground; a 4-horsepower gasoline engine; and a concrete reservoir 18.5 feet square and 3 feet deep. Cost of drilling well was $315; cost of pumping plant (not including well), $435. Well has been pumped continuously for 10 hours without noticeably affecting the supply. In test made August 30, 1914, 107 gallons was pumped in 21.5 minutes, making the rate of pumping about 5 gallons per minute.

7. Pumping plant consists of single-acting cylinder pump, cylinder with 8-foot suction pipe set 270 feet below surface of ground; an International 4-horsepower gasoline engine; and an elevated tank. Irrigates a small garden and about 30 peach trees. In test made August 28, 1914, almost exactly 20 gallons per minute was pumped.

8. Penetrated bed of caliche at 12 feet below surface. Water lifted by means of rope and bucket. Temperature of water, 79° F. Cost of well, $262.

15. Penetrated valley fill containing a bed of caliche, 10 feet below the surface, and two layers of gravel; the lower one, at a depth of 196 feet, yields water. Well ended in coarse cemented rock talus. Pumping plant consists of a single-acting cylinder pump (cylinder set 215 feet below surface), a 3-horsepower Fairbanks-Morse gasoline engine, and a 750-gallon elevated tank. Irrigated 6 acres of maize and melons in 1913. In test made August 27, 1914, 18 gallons per minute were pumped.

31. Well ends in conglomerate containing bowlders several feet in diameter. Yield of well reported to be 40 gallons per minute. Temperature of water 79° F.

37. Penetrated three strata of gravel; ended in fourth stratum. No casing used. Water reached at 118 feet below surface; rose rapidly within 108 feet of surface.

40. Well ends in water-bearing gravel. Pumping plant consists of a single-acting cylinder pump (cylinder with 15-foot suction pipe set 80 feet below surface), a 12-horsepower gasoline engine, and a 1,275-gallon elevated tank.

44. Two wells 10 feet apart. At depth of 103 feet reached bed of uncemented bowlders and sand, which could not be penetrated without casing. In one well this bed consisted almost entirely of bowlders, some of which required to be broken in order to be removed; in the other it consisted of sand and some bowlders 1 or 2 inches

in diameter. Pumping plant consists of single-acting cylinder pump in each well, both operated by gasoline engine. The two wells are said to have been pumped continuously for 5 hours, during which a combined yield of 100 gallons per minute was obtained.

46. Well ends in water-bearing conglomerate. Pumping plant consists of a single-acting cylinder pump (cylinder with 20-foot suction pipe set 120 feet below surface), a 4-horsepower gasoline engine, and a 1,275-gallon elevated tank.

48. Well ends in water-bearing conglomerate.

50. Dug to 69 feet; drilled to bottom. Penetrated alternating beds of clay and gravel, including four beds of water-bearing gravel. Pumping plant consists of a No. 5 vertical centrifugal pump with a rated capacity of 750 gallons per minute, set 69 feet below surface, and a 30-horsepower crude-oil engine. Drilled portion of well is cased, the upper 10 feet and lower 45 feet being perforated. Said to have been pumped at the rate of 900 gallons per minute for several hours without apparent effect on yield.

IRRIGATION.

Both the yield of wells and the ultimate supply of ground water will no doubt be found to be much less in Paradise Valley than in the Salt River valley, but the prospects for obtaining dependable supplies from underground sources for irrigation on a small scale are sufficiently encouraging to justify the sinking and testing of wells for this purpose.

Irrigation wells should be either dug or drilled to the water level and thence drilled a considerable depth into the zone of saturation in order to tap as large a section of water-bearing beds as practicable. The wells should be cased below the water level, and if drilled from the surface down they should be cased throughout. Double stovepipe casing not less than 8 or 10 inches in diameter, such as is used at the Phoenix waterworks and at other pumping plants in the Salt River valley, is probably best adapted for irrigation wells in Paradise Valley. At every satisfactory water-bearing bed the casing should be perforated with holes as large as the character of the sediments will permit and as numerous as is mechanically practical. After the casing has been inserted and perforated the well should be pumped long and hard in order to withdraw the fine sediments and to develop around the intake of the well if possible a cylinder of coarse, clean gravel that will yield water freely. Beds of fine sand that require strainers of fine mesh are not of much value for irrigation supplies.

Pumps adapted for lifting water for irrigation in this valley are vertical centrifugal pumps, generally of two or more stages; turbine centrifugal pumps; and deep-well cylinder pumps, preferably double-acting. If an ordinary vertical centrifugal pump is used the hole must be dug at least to the water level and the pump must be installed at or below this level. Two or more wells can be drawn upon with a single pump of this type if they are connected by tunnels at the water level, and suction pipes are extended from the pump, through the tunnels, into the accessory wells. Turbine pumps have the advantage that they can be inserted in wells that are only 12 inches or a little more in diameter, and that they can be set as far below the water level as desired, thus increasing the rate at which water can be drawn from wells of given specific capacity. The cylinder pumps are not easily kept in good repair and have other disadvantages, but if their valves are tight and the water is free of sand they have fairly high efficiency and are adapted for use in wells with small yields. Like the turbine centrifugal pumps, they can be placed as far below the water level as is desired.

On account of the great depths to the water table the cost of ground-water supplies will at best be high. This statement applies both to the original cost of wells and pumping plants and to the operating expenses.

At the O'Clair pumping plant, where the depth to the water is 195 feet (see table, p. 70), a 4-horsepower internal-combustion engine operating a deep-well cylinder pump lifts 20 gallons of water per minute. According to the owner, the engine consumes half a gallon of distillate per hour, and the cost of the distillate is 12 cents per gallon. At this rate the cost for fuel in pumping 1 acre-foot of water is $16.30. At the Williams plant, where the depth to the water level is 272 feet, a 4-horsepower engine operating a cylinder pump lifts 5 gallons of water per minute and is reported by the owner to consume one-fifth gallon of gasoline per hour at 20 cents per gallon, which represents a fuel cost of $43.50 per acre-foot of water pumped. At the Montgomery plant, where the depth to the water level is 196 feet, a 3-horsepower engine operating a clyinder pump lifts 18 gallons of water per minute, and is reported to consume only one-fifth gallon of distillate per hour, at 13 cents per gallon, the fuel cost being $7.80 per acre-foot of water. The data for the Montgomery well, if correct, however, imply an unusually high efficiency.

The above-cited data, which represent fairly well installed plants, show that pumping with internal-combustion engines where the lifts are from 200 to 300 feet is too expensive to be considered for the irrigation of even high-priced crops. With cheap electric power to be used in the lower part of the valley, where the depth to water is less, the problem, however, assumes a somewhat more hopeful aspect.

The electric transmission lines of the Salt River project run not far from Paradise Valley, and electric power could probably be obtained for pumping at about 1 cent a kilowatt-hour. At this rate, with a depth to the water level of 100 feet, a drawdown of 50 feet, and an efficiency of 40 per cent for the entire plant, the cost of power for pumping would be $3.65 per acre-foot of water lifted. Even this cost is high for the irrigation of ordinary low-priced crops requiring large amounts of water, but by thrift and good management it could be borne for the irrigation of crops that are valuable and do not require very large quantities of water. Such crops would also be best adapted to the small water supply.

Long-staple cotton, which is successfully grown in the Salt River valley, should be considered in this connection, as it requires only moderate amounts of water and would give not only rather large returns per acre but also fairly early and constant returns. Fruit growing, which under favorable conditions would give larger although more tardy returns, might be developed later to the extent that the climate is adapted to this industry and that adequate market facilities are provided.

SUMMARY OF CONCLUSIONS.

1. Paradise Valley is underlain by a deep deposit of detrital material, which in its lower part is saturated with water.

2. Within the zone of saturation there are water-bearing gravels which probably in part represent ancient channels of Cave Creek.

3. The water table, or upper surface of the zone of saturation, slopes southward at an average rate of about 5 feet to the mile, which is much less than the slope of the land surface. Along the Arizona canal the depth to the water table is 50 feet, or slightly more; toward the north it increases as the land surface rises, until along the abandoned Verde Canal it is nearly 300 feet.

4. In the region shown on the map (Pl. III) north of the Arizona canal and east of the Phoenix Mountains and Camelsback Mountain there are about 4,000 acres exclusive of the Indian reservation, or nearly 10,000 acres including the reservation, in which the depths to the water table are less than 100 feet; there are also about 20,000 acres, exclusive of the Indian reservation, or probably about 27,000 acres including the reservation, in which the depths to the water table range between 100 and 200 feet.

5. The ground water of Paradise Valley is supplied from the run-off and underflow of Cave Creek, the run-off from the mountain areas directly tributary to Paradise Valley, and the rain that falls on the valley.

6. The run-off and underflow of the drainage basin of Cave Creek north of Paradise Valley, an area of 225 square miles, are discharged into Paradise Valley. Although much of the run-off escapes from the valley through a gap in the Phoenix Mountains, considerable quantities sink into the gravelly deposits and are added to the ground-water supply. The buried gravel beds that are believed to mark the ancient channels of Cave Creek should be in a favorable position to convey this water to the lower parts of the valley.

7. The ground water of Paradise Valley is nearly or wholly inclosed by impervious bedrock except at the south end, where there is underflow into the Salt River valley.

8. There is no evidence of artesian structure in the valley fill nor in the surrounding bedrocks, and wells should be drilled with the understanding that pumping will be necessary.

9. Except near the Arizona canal the ground water is of good quality for domestic and industrial uses and for irrigation. Even in the vicinity of the canal it is believed to be usable for irrigation.

10. It is probable that the cleanly and sanitary bottling of Paradise Valley well water for sale in Phoenix and other points in the Salt River valley could be developed into a profitable and beneficial industry.

11. Both the yield of wells and the ultimate supply of ground water will no doubt be found to be much less in Paradise Valley than in the Salt River valley, but the prospects for obtaining dependable supplies from underground sources for irrigation on a small scale are sufficiently encouraging to justify the sinking and testing of wells.

12. On account of the great depths to the water table the cost of ground-water supplies will at best be high, but it is believed that if electric power is obtained at a low price, if crops are raised that are valuable and do not require very large quantities of water, such as long-staple cotton, and if thrift and good management are applied it will be practicable to pump the available supply of ground water for irrigation in the southern part of the valley.